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GEOHYDROTHERMAL MODEL OF ARJUNO, WELIRANG AND PENANGGUNGAN VOLCANOES EAST JAVA, INDONESIA

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Abstract

Indonesia is a country having a high geothermal energy potential. The geothermal energy in Java island, as a volcanic row island, has been explored and produced. One of the area that has not been produced is volcanic area around Arjuno, Welirang and Penanggungan (AWP) located in East Java. Geochemical survey has been performed to explore a more detailed objective in exploring the potential resource of geothermal energy of this area. Chemical and isotopic analysis shows the maturity level of waters taken from water springs in the area. The immature water from the water springs is interpreted coming mostly from meteoric water which flows quite fast forming water springs around the area. Geohydrothermally, the water flows through porous and permeable volcanic rocks that receive heat from igneous rocks existing together in the area. The igneous rocks are flowing heat conductively from magma below the AWP volcanoes.

Keywords: volcanic area, immature waters, geohydrothermal model

1. INTRODUCTION

With the growth of human population in Indonesia, the government of Indonesia has long developed the country, including increasing electric power generation. Geothermal electric generation has actually long been developed due to the fact about volcanic activity in Indonesia islands as of the result of tectonic and volcanic activities. The geothermal field that has long been developed since 1970s is Kamojang area, West Java. The following area that has been able to generate geothermal electric power are Salak, Darajat, Dieng, Lahendong, Ulubelu, and many others.

As a volcanic country Indonesia has significant geothermal energy resource potential. According to research and development that has been performed, it is known that geothermal resource potential in Indonesia reach approximately 27,791 MWe1).

Arjuno-Welirang-Penanggungan (AWP) volcanic area in East Java Province near Surabaya capital city has geothermal potential, shown by existence of hot water springs. Exploration activities have been conducted. This paper provides analysis and evaluation of research performed in 2016 in the area. Further and more detail exploration analysis may be conducted to explore more detail the area as well as capacity of possible potential in the area.

2. GEOLOGICAL OVERVIEW

Exploration survey has been performed in the area in early April 2016, beginning with field recognissance of the Arjuno – Welirang – Penanggungan geothermal area. Geological condition of the area must be firstly searched to expand the survey especially for geochemical and geophysical exploration of the area. Volcanological area is very specific of AWP geothermal area. Figure 1 shows specific morphology of the AWP volcanoes. Figure 2 and 3 provide geological map and cross section of the AWP geothermal survey area.

Hot springs appear in the western part of Arjuno-Welirang volcanoes indicates the possible resource of geothermal energy underneath the area. Although the volcanic rocks are mostly of Quarternary age, the existence of heat source from the magmatic source could be explored further to explore the geothermal potential of the area.

Figure 1: Morphology of Arjuno-Welirang-Penanggungan volcanic complex having geothermal surface manifestation signs in the area

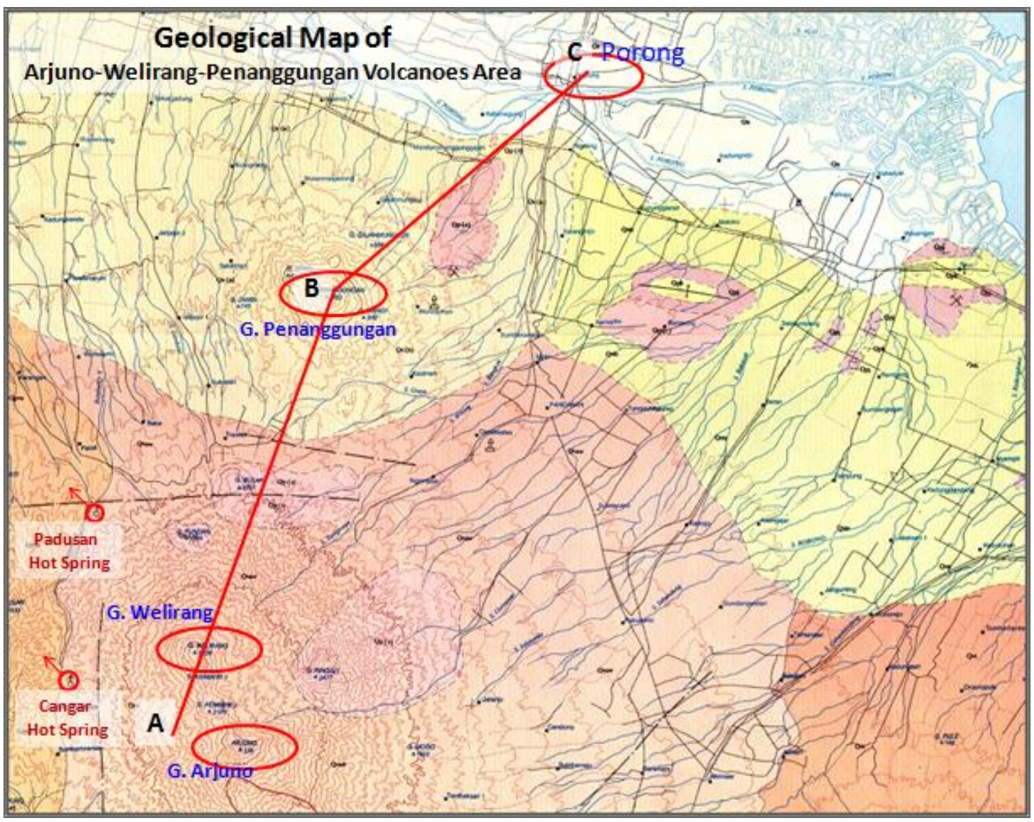

Figure 2: Geological map of Arjuno-Welirang-Penanggungan and Porong Area.

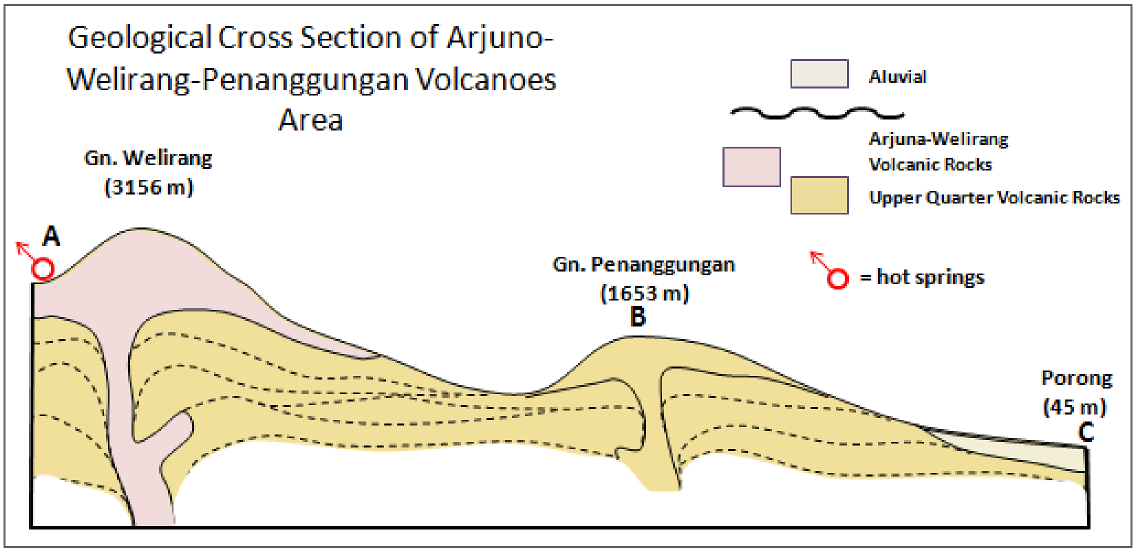

Figure 3: Geological cross section of Arjuno-Welirang-Penanggungan up to Porong area

3. GEOCHEMICAL RESEARCH

A geochemical survey has been performed by taking fluid samples from water springs surrounding the AWP geothermal area. From each location, two samples are taken for isotopic and chemical lab analysis. Table 1 shows geographic position location data of the springs where the samples are taken from the AWP geothermal area. Table 2 provides isotope analitical result ($\delta^{18}O$ and δD) from water samples taken in the field, while Table 3 presents result of general chemical lab analysis.

Chemical Analysis Results:

Tabel 2:
Outcome of $\delta^{18}O$ and δD chemical lab analysis
of water samples from AWP and surrounding area.

No.	KodeSampel	$\delta^{18}O$ (‰)			δ D (‰)		
1	WS Jedong Temple 020416	-8.79	±	0.56	-49.2	±	2.6
2	HWS Cangar 020416	-9.30	±	0.27	-59.5	±	1.1
3	WS Wonosunto 030416	-7.26	±	0.20	-43.0	±	0.7
4	WS Candi Jolotundo 030416	-6.83	±	0.26	-45.3	±	1.1
5	WS around Coban Canggu Mojokerto	-7.26	±	0.35	-49.4	±	1.8
6	Hot water from Porong mud	+7.39	±	0.47	-20.0	±	5.7
7	WS PadusanPacet	-9.91	±	0.47	-69.2	±	1.7
8	WS of BruganTrawas 020416	-6.05	±	0.12	-36.4	±	0.4

*) WS = Water Spring, HWS = Hot Water Spring

Table 1: Water samples from survey location around Arjuno-Welirang-Penanggungan volcanoes, south west of Porong

No	Water Source	Location (Village)	District & Regency	Geographic Positioning System & Topography			pH	Temp (^{0}C)	Notes
				LS (S) (..^{0}-..′-..″)	BT (E) (..^{0}-..′-..″)	Elevasion (m)			
1	Water spring on water fall	Cuban Canggu	Pacet, Mojokerto	07-40-54,44	112-32-47,51	771	6	21	Soth-West of G.Welirang
2	Hot spring	Padusan	Pacet, Mojokerto	07-41-14,59	112-32-59,57	887	6-7	55	West of G.Welirang
3	Water spring	Sendang	Trawas, Mojokerto	07-38-03,44	112-35-50,60	510	7	25	Slope of Penanggungan Mount
4	Water spring	Jolotundo Temple	Trawas, Mojokerto	07-36-35,72	112-35-44,81	556	6	22	Between Penanggungan Mount -Welirang
5	Water spring	Near Jedong Temple	Trawas, Mojokerto	07-34-47,44	112-36-50,56	239	5,5	23	North slope of Penanggungan
6	Hot spring	Cangar	Pacet, Mojokerto	07-44-31,80	112-32-01,01	1568	7	55	Warm water bath pool of R.Soerjo Forest Park
7	Hot water from flowing mud	Mud crater	Porong, Sidoarjo	07-31-53,28	112-42-29,62	45	7-8	50	Mug flow from Banjarpanji-1 well
8	Water spring	Near Belahan Temple	Gempol, Pasuruan	07-37-35,05	112-39-01,21	347	5,5	23	Eastern slope of G.Penanggungan

Table 3. Lab Chemical Analysis Results of Water Samples from the AWP and surrounding area

No.	Sample Code	Ca^{2+}	Mg^{2+}	K^+	Na^+	HCO_3^-	Cl^-	SO_4^-
		(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
1	WS Jedong Temple 020416	24.9	7.9	4.4	12.4	331.3	5.5	3.7
2	HWS Cangar 020416	135.7	119.9	35.9	121.8	804.7	31.2	82.9
3	WS Wonosunto 030416	27.0	8.2	1.9	8.7	213.0	3.1	1.9
4	WS Candi Jolotundo 030416	15.9	3.7	3.7	6.6	189.3	2.0	1.7
5	WS around Coban Canggu Mojokerto	36.7	17.3	9.3	38.6	280.4	16.6	20.9
6	Hot water from Porong mud	1159.7	209.6	158.3	7807.8	544.4	11049.1	114.9
7	WS PadusanPacet	214.2	148.3	60.0	258.5	5017.9	154.2	164.2
8	WS of BruganTrawas 020416	40.2	9.9	3.3	10.0	236.7	2.8	3.9

*) WS = Water Spring, HWS = Hot Water Spring

4. GEOCHEMICAL DATA ANALYSIS

4.1. Geothermometer

Chemical data and isotopic analysis using data from water samples analysis have been performed. Early subsurface temperature of the geothermal system may be predicted by geothermometer method developed by geothermometer experts i.e. using Na, K, Ca, and Mg (Fournier & Truesdell, 1973, Fournier, 1983, Truesdell, 1976, and Giggenbach, 1988). The water sample taken from mud flow of Porong mud pool is not included in the analysis shown in Table 4. This is because the sample location is far from the AWP mountain geothermal area (approximately 45 km). Geologically the location is originally an oil exploration field. In fact, the mud pool also contain crude oil coming from seepage or drips of possible oil reservoir beneath Porong and Banjarsari field. Therefore, the fluids coming out of the Porong location is not originally representative of geothermal field.

Table 4 provides the result of the above geothermometer analysis. From the calculation of seven samples fluid chemical data there seems an extreme difference between geothermometer developed by Fournier & Truesdell (1973) and Giggenbach (1988) with the result of geothermometer by Fournier (1983) dan Truesdell (1976). Two elements Na and K are relatively stable elements in a temperature changes. Therefore, geothermometer calculation of Fournier (1983) dan Truesdell (1976) are estimated to be more representing the subsurface condition around the AWP geothermal field. With this estimation, the subsurface temperature of AWP geothermal area could reach as high as 300 to 350^{0}C.

4.2. Water Maturity

According to the method developed by Giggenbach (1988), plotting of Na, K, and Mg elements in triangular curve is performed with a result shown in Figure 4. From this figure it seems that the sample fluids are still immature fluids. This condition is estimated as a result of the possibility that the fluids are originated from meteoric fluids that has been permeated quickly in close distance for example from rain and fluvial water that permeated down earth and contact with hot igneous rock of AWP volcanic intrusions. This contact of meteoric water and hot igneous rock results in increasing the temperature of the meteoric water, that resulting flowing the fluid to the surface to become hot springs. This happens for example in hot springs of Cangar and Padusan Pacet area that located near the top of Welirang volcano as shown in Figure 2 and 3.

Tabel 4: Geothermometer of water samples from the AWP and surrounding area

No.	Sample Code	Geothermometer			
		Na-K-Ca Fournier & Truesdell (1973)	Na-K Fournier (1983)	Na-K Truesdell (1976)	K-Mg Giggenbach (1988)
1	WS Jedong Temple	175,40	356,45	381,80	37,53
2	HWS Cangar	170,91	331,25	343,76	30,66
3	WS Wonosunto	147,56	294,54	290,84	45,91
4	WS Jolotundo Temple	199,22	428,56	499,17	35,58
5	WS Coban-Canggu (near water fall)	162,01	306,07	307,15	34,18
6	HWS Padusan Pacet	161,32	301,64	300,84	27,00
7	WS Near Rest Brugen Trawas	165,51	346,35	366,38	41,39
	Average Temperature (degr C)	168,85	337,84	355,71	36,04

4.3. Fluid Types

Other chemical analysis has also been performed. Triangular curve of Cl, SO4, and HCO3 anions has been plotted based on a method developed by Arnorsson (1988). This method will provide the type of geothermal fluid source that have been taken their samples for the analysis. Figure 5 presents the Triangular curve of Cl, SO4, and HCO3 anions.

From Figure 5 it also can be seen the type of geothermal fluids which are included in Peripheral Waters, the type that in cross different with Mature Waters. Applying this analysis is also in accordance with Triangular curve of Na-K-Mg. It is interpreted that the fluids appears from the springs have not long been flown underground. It is flowing in short time due to relatively short time flow of rain water and high volume of fluvial water underground seepages around the Arjuno-Welirang-Penanggungan volcano area.

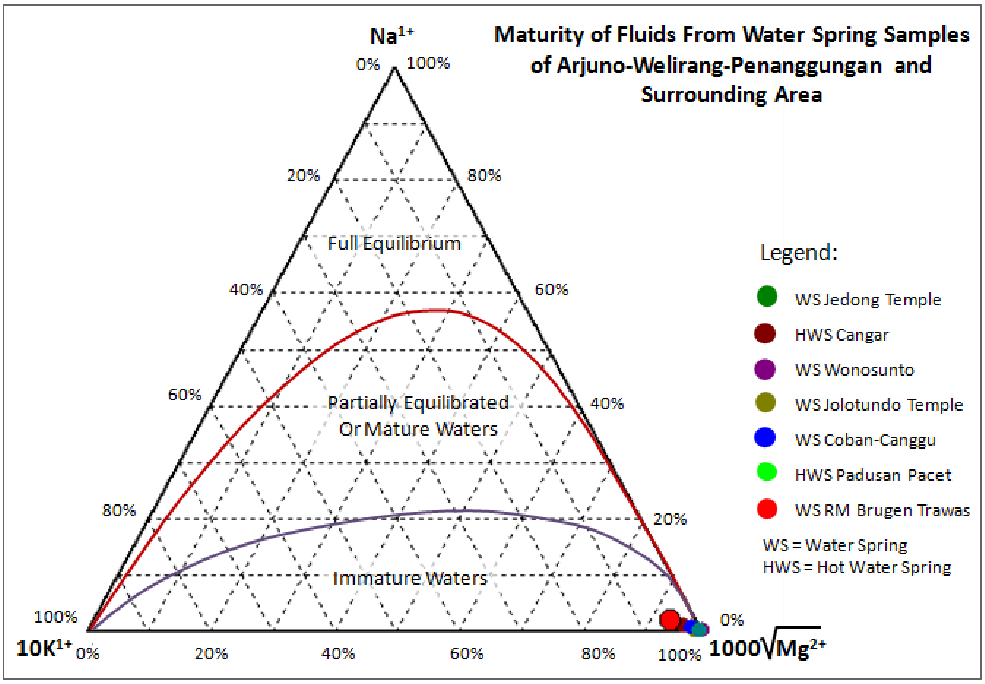

Figure 4: Na-K-Mg Triangular curve (eg. Giggenbach, 1988) using chemical data of geothermal water spring fluids taken from Arjuno-Welirang-Penanggungan volcanoes area.

4.4. Upflow and Outflow Geothermal Fluid Analysis

Using the above available chemical data, analysis of possible geothermal fluids upflow and outflow has been performed. By knowing the decrease or increase of certain chemical concentrations are selected. Four analysis were conducted. Table 5 to 8 (enclosed) show possible fluid flow using chemical element concentration ratios. From this analysis it can be predicted where and how the possible underground geothermal fluid flow direction whether upflow or outflow around AWP area.

4.5. Isotopic Analysis

The water fluid types can be analyzed using isotopic characteristics. Isotopic lab analysis has also been performed to the spring water samples taken in AWP area. Figure 6 shows plot of Deuterium and Oxygen isotops using data from Table 2.

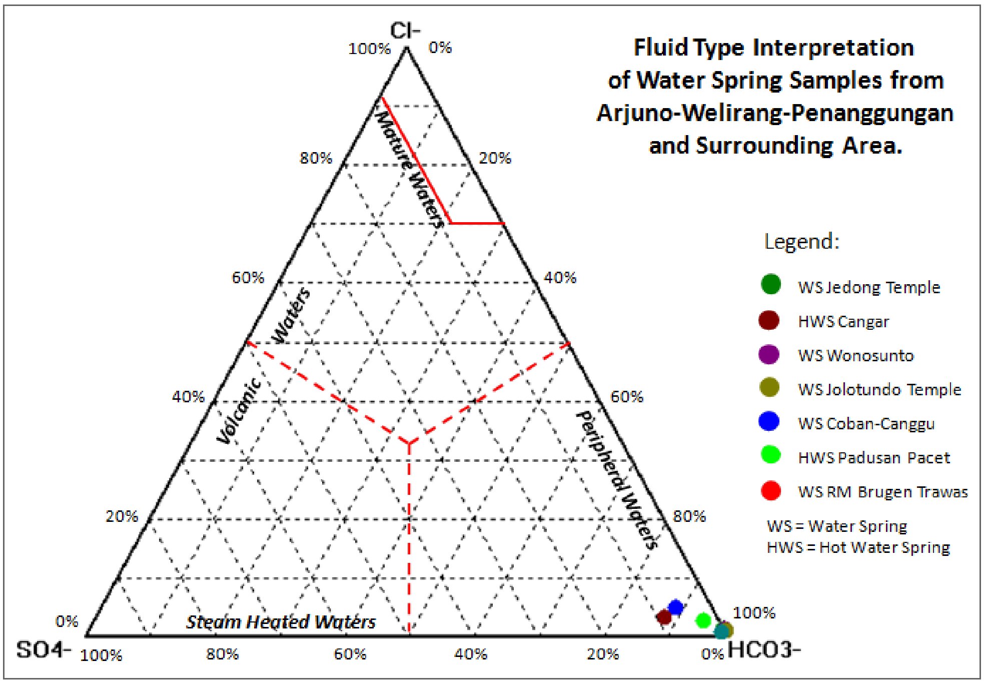

Figure 5: Cl, SO_4, and HCO_3 Triangular curve (eg. Arnorsson, 1988) using chemical data of geothermal waterspring fluids taken from Arjuno-Welirang-Penanggungan volcanoes area.

From the isotopic curve in Figure 6 it is clearly seen the trend of local spring water characteristics of AWP area. The trend of geothermal water line of AWP area almost fit to Meteoric Water Line trend, but still far from Magmatic (Andesitic) water of the area. From this feature it can be inrpreted that there was not much mixing of meteoric water and magmatic water. It is even predicted that the spring water is dominated by meteoric water coming from rain as well as fluvial water from surrounding the AWP area. This indicates that the local AWP geothermal water is much coming from meteoric water that precipitates underground from surface, touching hot igneous rocks, then flows up to the surface forming hot springs near Welirang volcano.

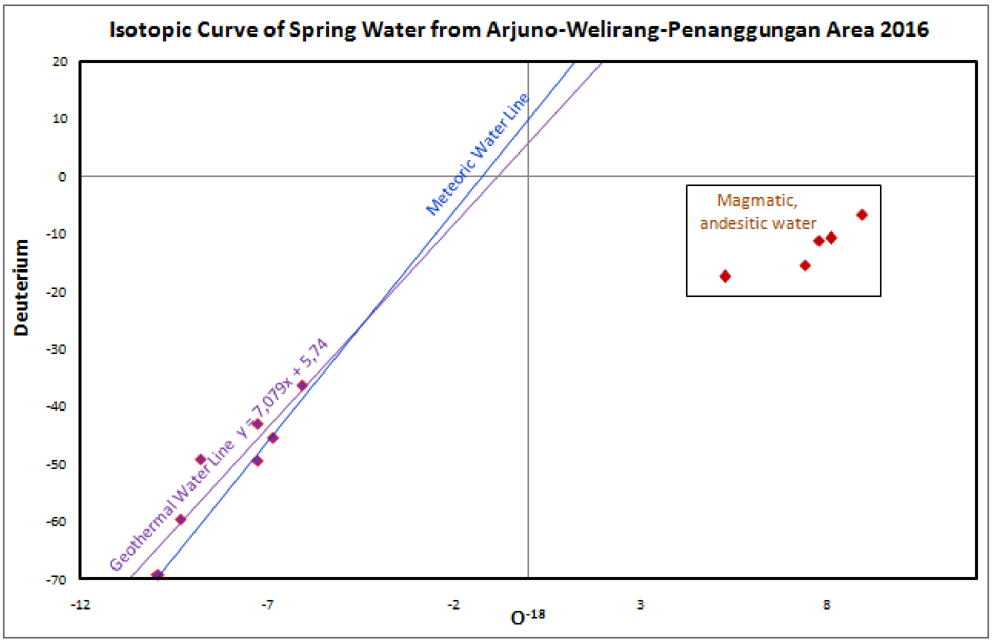

Figure 6: Isotopic curve of Deuterium and Oxygen using data from Arjuno-Welirang-Penanggungan volcanoes area (Table 3).

4.6. Geothermal Modeling

Using the above geological as well as geochemical data, information and evaluation, it can be analyzed the possible geohydrothermal model of the AWP area. As described in the geological data and analysis, the rocks dominantly exist in the AWP area are Quarternary volcanic and igneous rocks. Figure 2 and 3 present the geological condition in the area.

Using geographic positioning system data taken while survey in the field is used to configure the location of geological position of fluid samples taken from the Arjuno-Welirang to Penanggungan mountains. Figure 7 shows where relatively hot and cold surface temperature springs are found. The surface temperature may also be used as data to interpret the upflow and outflow zones of the geothemal system developed in the area as shown in Figure 8.

Because of the young age and lithification level, the geothermal area rocks are composed of igneous and volcanic rocks. Figure 8 provides the illustration of cross section between Mount Welirang to Mount Penanggungan and up to south west Porong area. The figure also presents rocks types below the area as depicted in Figure 3. The igneous rocks could be formed by intrusion and extrusion of subsurface magma in the AWP mounts, forming lava flow as well as intrusive rocks below the area. While the extrusive rock were generated by explosion of the volcano's magma, forming fragmented grains to product breccia, sand, and tuff deposits. As the volcanism activity decline, the deposits become porous and permeable young volcanic extrusive rocks.

As shown in Figure 8, the compact and cristalline igneous rocks may be function as heat conductor from subsurface magma source, while the porous and permeable volcanic rocks transform the water from rain fall and fluvial surface river that precipitates and flows down from surface. This seapaged water will transport to reach hot igneous rocks to become hot water. Further the heat will expand the water volume to become less heavy water and easily flow back up to the surface. When it reach the atmospher it forms hot springs such as the ones present in Padusan and Cangar hot springs in western area of Welirang Mount.

Triangular curve shown in Figure 4 provides the maturity of the most water taken from the springs around the AWP area. The relatively short distance and the time of water flow from surface down to the heat source and back up flows to the surface will product hot water that is relatively young age to become immature water. Meanwhile Figure 5 shows the fluid types of most water from the springs around the AWP area, which belongs to peripheral waters type.

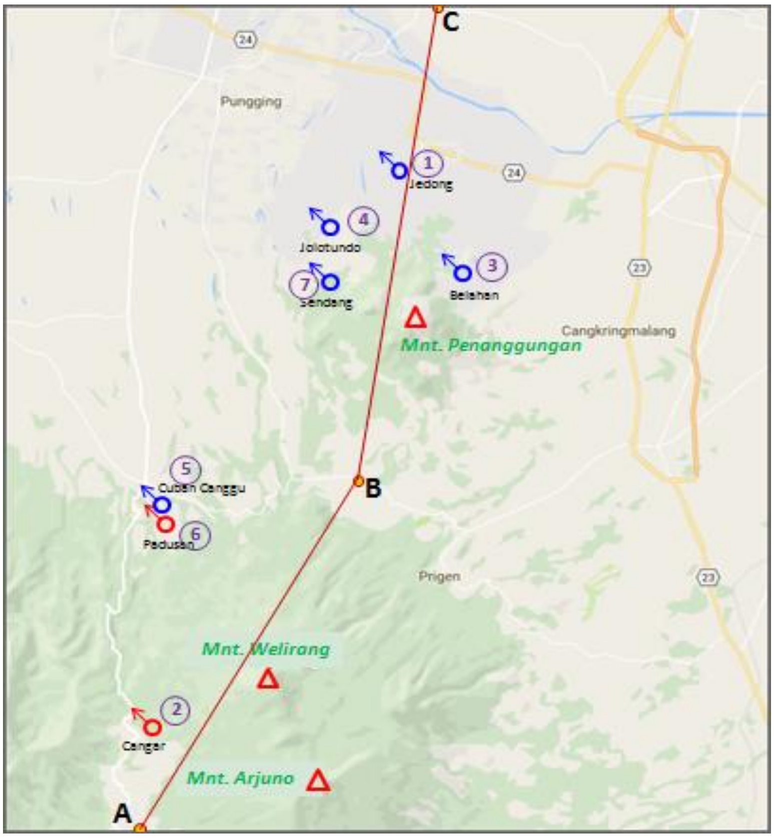

Figure 7: Location map of geothermal water samples taken from water springs in the Arjuno-Welirang-Penanggungan geothermal area, East Java, Indonesia

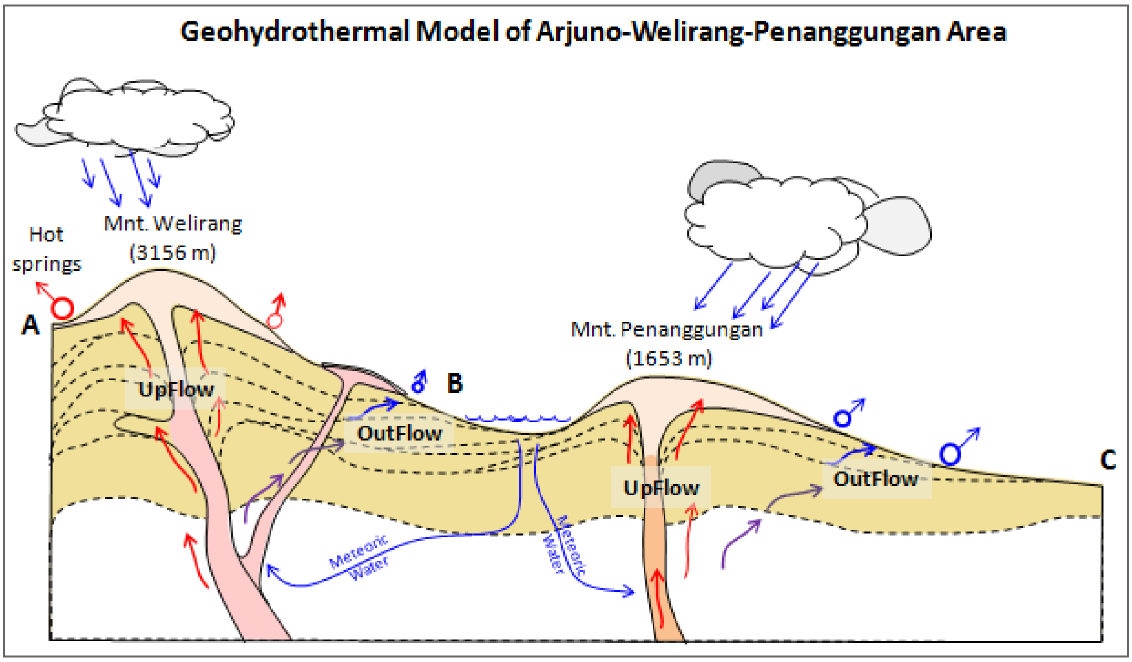

Figure 8: A-B-C cross section of the AWP geothermal area showing geohydrothermal model of water springs around Arjuno-Welirang-Penanggungan area.

I. Conclusion and Recommendation

Geothermal exploration survey has been performed in Arjuno-Welirang-Penanggungan volcanic area, East Java. It can be concluded that,

1) Geothermal manifestation of hot water springs, rock alteration, and other typical geothermal manifestation can be found in the area. Samples from water springs in the area have been taken for geochemical analysis and evaluation.
2) Geochemical analysis data analsis shows that the spring waters are dominantly immature, shows up from meteoric water that has been heated by hot conducted subsurface igneous rock and flows up to the surface through porous and permeable volcanic rocks forming hot water springs.
3) The subsurface water flow that are not heated has flown through porous and permeable volcanic rocks to form cold water springs far from heat source below Welirang-Arjuno volcanoes.
4) Further searches could be performed to evaluate and analyse the energy (heat) potential of the AWP geothermal area.

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Appendix:

Table 5: Geothermal fluid flow using concentration ratio of Na/K

No.	Sample Code	Na^+ (ppm)	K^+ (ppm)	Na/K Ratio	Flow Direction
4	WS Jolotundo Temple	6,6	3,7	1,783784	upflow
1	WS Jedong Temple	12,4	4,4	2,818182	
7	WS Brugen Trawas (Sendang)	10,0	3,3	3,030303	
2	HWS Cangar	121,8	35,9	3,392758	
5	WS Coban-Canggu	38,6	9,3	4,150538	
6	HWS Padusan Pacet	258,5	60,0	4,308333	
3	WS Wonosunto (Belahan)	8,7	1,9	4,578947	outflow

Table 6: Geothermal fluid flow using concentration ratio of SO_4/HCO_3

No.	Sample Code	SO_4^- (ppm)	HCO_3^- (ppm)	SO_4/HCO_3 Ratio	Flow Direction
2	HWS Cangar	82,9	804,7	0,10302	upflow
5	WS Coban-Canggu	20,9	280,4	0,074536	
6	HWS Padusan Pacet	164,2	5017,9	0,032723	
7	WS Brugen Trawas (Sendang)	3,9	236,7	0,016477	
1	WS Jedong Temple	3,7	331,3	0,011168	
4	WS Jolotundo Temple	1,7	189,3	0,00898	
3	WS Wonosunto (Belahan)	1,9	213,0	0,00892	outflow

Table 7: Geothermal fluid flow using concentration ratio of Cl/SO_4

No.	Sample Code	Cl (ppm)	SO_4^- (ppm)	Cl/SO_4 Ratio	Flow Direction
3	WS Wonosunto (Belahan)	3,1	1,9	1,631579	upflow
1	WS Jedong Temple	5,5	3,7	1,486486	
4	WS Jolotundo Temple	2,0	1,7	1,176471	
6	HWS Padusan Pacet	154,2	164,2	0,939099	
5	WS Coban-Canggu	16,6	20,9	0,794258	
7	WS Brugen Trawas (Sendang)	2,8	3,9	0,717949	
2	HWS Cangar	31,2	82,9	0,376357	outflow

Table 8: Geothermal fluid flow using concentration ratio of Na/Ca

No.	Sample Code	Na (ppm)	Ca (ppm)	Na/Ca Ratio	Flow Direction
7	WS Brugen Trawas (Sendang)	10,0	40,2	0,248756	upflow
3	WS Wonosunto (Belahan)	8,7	27,0	0,322222	
4	WS Jolotundo Temple	6,6	15,9	0,415094	
1	WS Jedong Temple	12,4	24,9	0,497992	
2	HWS Cangar	121,8	135,7	0,897568	
5	WS Coban-Canggu	38,6	36,7	1,051771	
6	HWS Padusan Pacet	258,5	214,2	1,206816	outflow